International Journal of Physics
and Research (IJPR)
ISSN (P): 2250-0030; ISSN (E): 2319-4499
Vol. 9, Issue 1, Jun 2019, 31-38

MORPHING OF AIRCRAFT WING ACCOMPANYING ELECTRORHEOLOGICAL FLUID CONTROLLED ACTUATORS

MADHAN KUMAR. G, VIJAYASEKAR. S, VAIGUNTHAVASAN. N, KABILAN. T, BHARATHIVARMAN. R & MANIVEL. A

Surya Group of Institutions, Affiliated to Anna University, Vikravandi(Po), Villupuram, Tamil Nadu, India

ABSTRACT

Electro-rheological fluid (ER) technology is an old ''newcomers'' coming to the market at high speed. Various industries including the automotive industry, production sector, and robotics are full of potential ER fluid applications. A structure based on ER fluids might be the next generation in design for products where power density, accuracy and dynamic performance are the key features. Previous studies of Electro-Rheological fluid were motivated by brake, clutch, damping and resistive application instead of an ER Fluid based electrode actuator. To fully understand the performance of such an actuator, it is imperative to study ER fluid combinations and performance. The novel method of introducing the exact ER fluid into the aircrafts conventional control surface system instead of hydraulically or pneumatically operated fly-by-wire or fly-by-light system. This paper presents the working principle, methodology of preparation in low cost, physical and chemical properties and quick response control of ER fluids. This work also shows the excellent features like fast response, simple interface between electrical power input and the mechanical power output and controll ability make ER Fluid the next technology of choice for many applications.

KEYWORDS: Electro-Rheological Fluid, Smart Fluid in Wings, Aircraft Wing Actuators, Morphing Wing, Micro Fluidics, Controllers & Pitching Moment

Received: Apr 02, 2019; **Accepted:** Apr 22, 2019; **Published:** May 25, 2019; **Paper Id.:** IJPRJUN20194

Original Article

INTRODUCTION

To improve aerodynamic performance, the use of bionics in aircraft design is being considered. Swifts control their glide performance by changing the geometry of their wings; for example, they adjust their wing sweep to suit the speed. Jackdaws and other birds maneuver in flight by changing the geometry of their wings and tail. It follows that morphing wings canplay a very important role in air craft design. A number of aircraft with morphing wings have been designed and produced since World War II are expired due to high maintenance cost and services. Currently, piezoelectric, magnetostrictive, and ferroelectric materials, optical fibers, Electrorheological (ER) and magnetorheological (MR) fluids, shape memory alloys, shape memory polymers, electro-active polymers, and multifunctional nano-composites can be considered as smart materials and fluids used for morphing technology. In order to develop the conventional controls new technologies are invented. This paper presents the techniques of introducing the ER fluids in conventional wings and the process of functioning the actuators are studied.

REVIEW OF ER FLUIDS AND ITS PROPERTIES

The more extensive change in dynamic yield strength for electro rheological fluids is primarily due to change in conductivity and relative permittivity of the particles and oil components of the fluid over the temperature. One of the most important properties of an electrorheological fluid is its dynamic yield stress, which

is the minimum stress required to cause the fluid to flow under the applied field. Usually, higher dynamic yield stress is desired and in current electro rheological fluids they range approximately 100Pa to over 3KPa. ER fluid flows between two electrode plates freely with low viscosity in configuration has zero potential across the electrodes, while the configuration has 750 V of voltage potential across a 0.25-mm gap, which produces electric field (E-field) of 3 kV/mm shows a heuristic behaviour.

The study of the structure and function of living things as model for the creation of materials or products by reverse engineering (David, 1999). The ER Fluid shows that excellent features like fast response, simple interface between electrical power input and the mechanical power output and controllability make them as the nexttechnology of choice for many applications (Jadhav, 2012). The numerical simulation results that flapped morphing wings have a better aerodynamic performance when compared to twisted wings and different morphing levels can be achieved using lighter smart materials with lower specific energy for this configuration (Donadon, 2014). The newtest successfully measured the dynamic viscosity of the ERF to beat 0.6 Pa-s for low flow rates and 0.2 Pa-s for higher flow rates. The presented valve design can successfully resist 1 MPa of fluid pressure, which is an operation mode higher than any haptic anddamping applications in the literature (Quang, 2015). The springs were arranged in an upper and alower layer to cause rotation of the flap in both the upward and downward directions. The spring actuators were controlled by the introduction of heat resulting from the applied current (Hutapea, 2016). Recent developments in the application of smart materials and structures to morphing aircraft are reviewed. Specifically, four categories of applications are discussed: actuators, sensors, controllers, and structures (Jian Sun, 2016). The method of plotting the NACA 4 digit airfoil and pressure distribution around it at zerodegree of angle of attack and the obtainedresults are compared and contrasted with experimental and computational calculation (Madhan Kumar, 2018). In this work, the morphed wing aircraft model is kept inside the wind tunnel and the pitching moment and hinge moment coefficients are calculated for various angle of incidence and flap deflection.

PH test and Electrode test are carried out for testing the ER fluid and its responses. The response of flapped ER fluid model hinge moment coefficients are calculated for every angle of incidence. The values of hinge moment coefficients are explicity plotted and compared with the conventional control wing model to prove the higher response timing and active vibration control.

ERF MODEL SPECIFICATION AND SELECTION

ER fluid is prepared bya combination of different carrier fluid and solid additive material to yield the perfect colloidal solution. The basic combination of additives such as potato starch, maize starch and corn flour and carrier fluids such as sun flower oil, paraffinoil, silicon oil and vegetable oil of different combinations are validated for selection of best ER fluid model that should be considered for the morphing aircraft wing model. The basic chemical test such as PH test and electrode test for 12 different ER fluid models are tested to select the best ER fluid for morphing wing technology.

From the PH test, all combination are base fluids of different concentrations. Among them the fluid with high and moderate concentration could exhibit the rheological properties. The best ER fluid model is combination of potato additives and paraffinoil having high and moderate concentration for electrical conductivity. Few fluids having less colloidal suspension are not dissolved perfectly and solid particles are suspended.

The electrode test with the primary assumption that treating the ER fluid as the dielectric medium which are carried between the copper plates. Since ER fluidis acting as a dielectric, the dielectric constant (K), permitivity constant (ε_0), Fluid immersed area (A), distance between the electrode plates (D) and dielectric capacitance are calculated using the formula,

Capacitance, $C=K\varepsilon_0 \frac{A}{D}$ 1

The charge of an electric field produces across the electrodes are calculated as,

$Q=CV$ 2

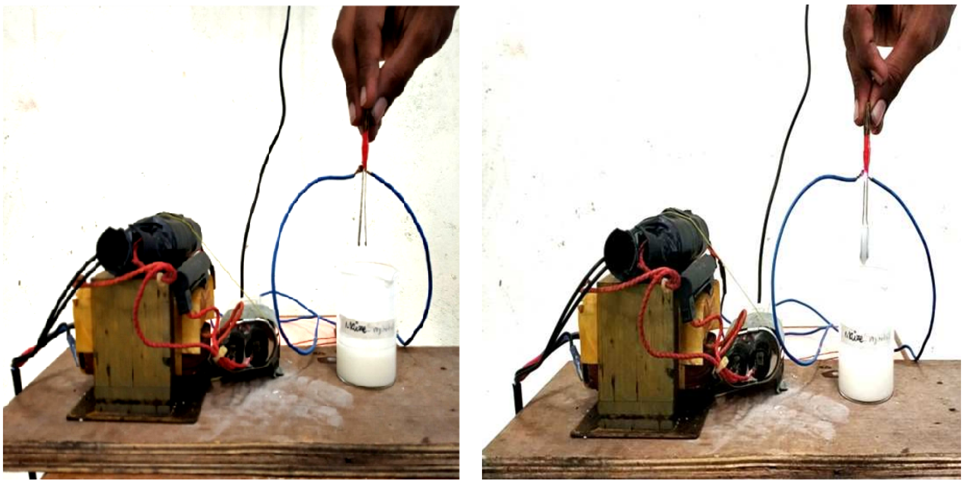
The electric field applied between the electrodes by applying 5000 V DC without contact of fluid i.e. the free electrode electric field are calculated as,

$\vec{E}_0=\frac{Q}{K\varepsilon_0 A}$ 3

Thus the electric field applied between the electrodes carrying dielectric fluid i.e. ER fluid is calculated as,

$\vec{E} \;=\frac{\vec{E_0}}{K}$ 4

Electric field supplied without contact of ER fluid is calculated around $1.25\frac{kv}{mm}$, when this electric field is applied to ER fluid sudden potential drop occurs between electrodes, which increases the yield strength of the fluid and the electric field consumed is around $0.625\frac{kv}{mm}$for 4mm electrode gap as shown in Figure 1. (b). When zero electric field is applied between the electrodes, there is no increase in shear stress of the fluid as shown in Figure 1. (a).



(a) **(b)**

Figure 1: (a) Zero Electric Fiel Dresponse Slow Viscosity (b) 0.625 Kv/mm Electric Field Responses High Viscosity

ER FLUID EFFECT IN MORPHING WING TECHNOLOGY

The morphing wing model designed with NACA 4412 airfoil utilizing balsa wood which could be fabricated using emery sheet and selecting the flapped egion of the wing model in which it carries Electro-rheological fluid (potato+paraffinoil) in between the two copper plate. The copper plates are applied with DC electric ield of 1.25 kV/mm to

control the Electro-rheological fluid by shear mode operation. This undergoes pitching up as shown in Figure 2. (a) and pitching down as shown in Figure 2. (b) throughout the morphed wing model which was tested inside the wind tunnel.

The pitching moment coefficient and hinge moment coefficient is calculated using the formula given by thin airfoil theory, as follows :

Pitching moment coefficient = $\frac{x}{c}(C_L \cos\alpha + C_D \sin\alpha)$ 5

Hinge moment co-efficient $= b_1\alpha + b_2\eta$ 6

Where,

$b_1 = -\frac{1}{4F^2}\{2(\pi - \phi)(2\cos\phi - 1) + 4\sin\phi - \sin 2\phi\}$

$b_2 = -\frac{1}{4\pi F^2}\{(1\text{-}\cos 2\phi)\text{-}2(\pi - \phi)2(1\text{-}2\cos\phi)\text{+}4(\pi - \phi)\sin\phi\}$

(a) (b)

Figure 2: (a) Pitching up (Downward Flap Action) (b) Pitching Down (Upward Flap Action)

The flap morphed wing model and conventional wing model is tested inside the wind tunnel to find the lift, drag, pitching moment co-efficient (equation 5.) and hinge moment co efficient (equation 6.) with the help of three component wind tunnel balance and torque meterat different angle of incidence like 0^0, 2^0, 4^0, 8^0 & 15^0 atvarious flow speed of control such as 10, 20, 30 & 40 m/sto check the quick response behavior or quick response control through shear mode operated electro-rheological controller and to show that the quick reponseis better than the conventional one.

QUICK RESPONSE RESULT OF ER FLUID CONTROLLER

The pitching moment coefficient and hinge moment coefficient of flap morphed wing model carrying ER fluid controller is recorded inside the wind tunnel for different angle of incidence and it is plotted as shown in Figures 3, 4, 5, 6 and 7. The pitching moment coefficient of conventional wing model is also recorded inside the tunnel and it is compared with the flap morphed wing. These results shows that flap morphed wing provides quick response of high hinge moment coefficient and pitching moment coefficient for different angle of incidence than the ordinary conventional wing model.

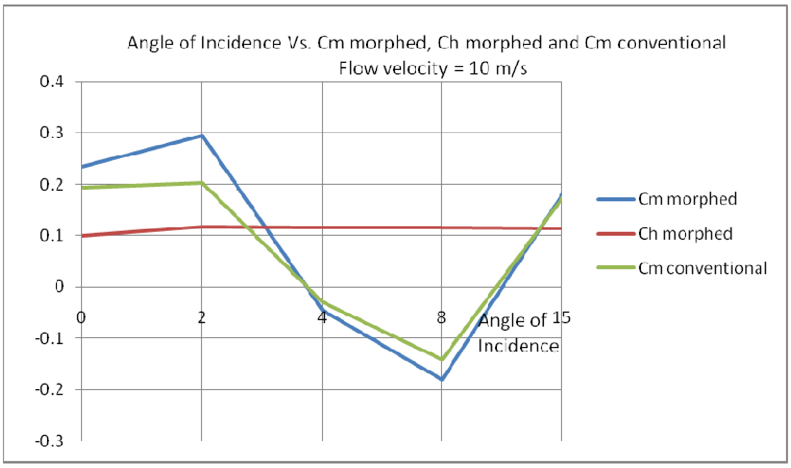


Figure 3: Pitching Moment and Hinge Moment Coefficient of Flapmorphed and Conventional Wing Recorded at Flow Velocity 10 m/s

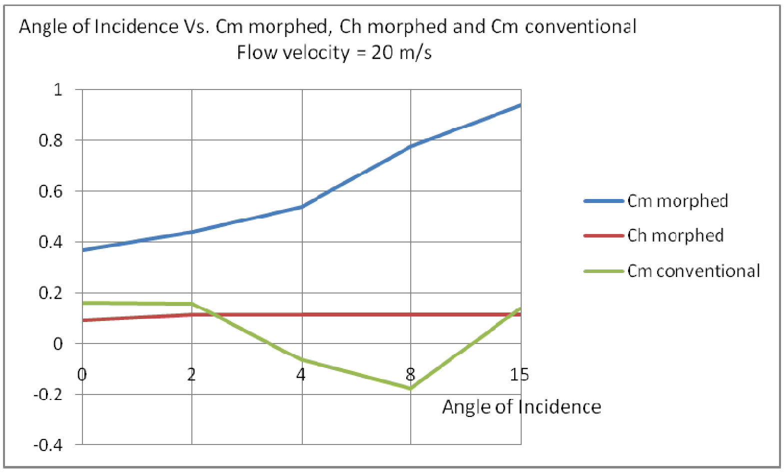


Figure 4: Pitching Moment and Hinge Moment Coefficient of Flap Morphed and Conventional wing Recorded at Flow Velocity 20 m/s

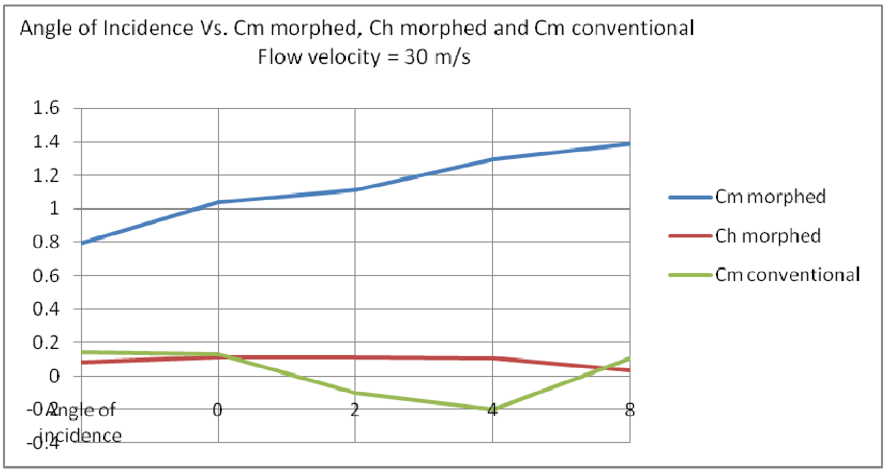


Figure 5: Pitching Moment and Hinge Moment Coefficient of Flap Morphed and Conventional Wing Recorded at Flow Velocity 30 m/s

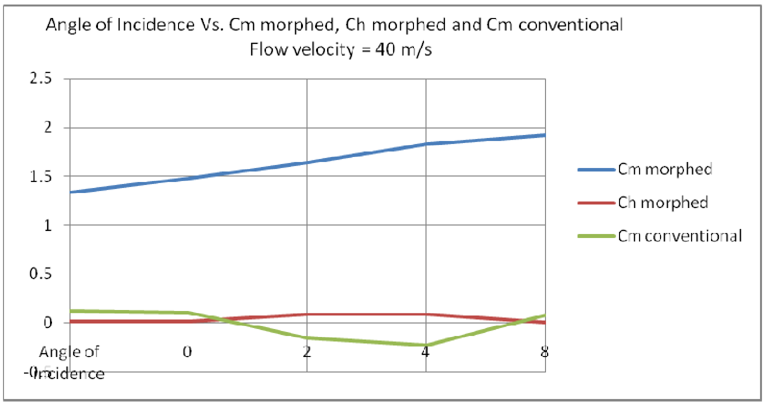


Figure 6: Pitching Moment and Hinge Moment Coefficient of Flap Morphed and Conventional Wing Recorded at Flow Velocity 40 m/s

The hinge moment coefficient for flap morphed wing at different flow velocities at different angle of incidence are plotted in Figure 7 shows that the hinge moment coefficient is larger at low flow speeds and it is smaller at high flow speeds at different angle of incidence. Thus the hinge moment coefficient responses quickly on heavy loads acting over the wing surface at high flow speed.

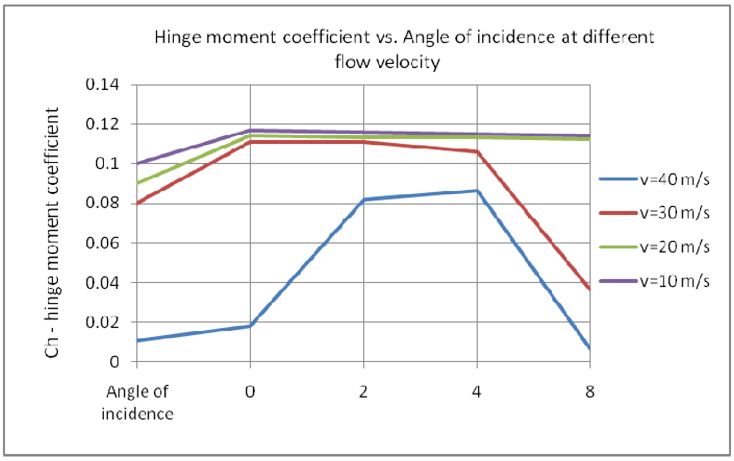


Figure 7: Hinge Moment Coefficient of Flap Morphed Wing at Different Angle of Incidence and Flow Speeds

CONCLUSIONS

- The various positions of upward and down ward deflection of wing and its lift and drag estimation are empirically calculated for flap morphed wing model containing ER Fluid as well as conventional wing model of similar configuration to validate the lift[7], pitching moment[7] and control hinge moment co-efficient thoroughly
- Thus the obtained results of flap morphed wing model containing ER fluid possess quick response which produces high L/D ratio in short period of control hinge moment and proved that the ER fluid controller acts as a high dynamic response of the wing model configuration.
- The further extension of this work includes ER fluid servicing time, controlling the aircraft wing model with the control stick assisting fly-by-wire or fly-by-light system control systems, feedback, sensitivity and rate of control as an active vibration control in all dynamic responsing conditions of UAV or any aircrafts.

ACKNOWLEDGEMENTS

Authors are greatful to Tamil Nadu State Council for Science and Technology, DOTE Campus, Chennai for providing financial assistance to carried out the project work.

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